

## MASTER PLAN FOR GEOTHERMAL AND HYDROPOWER DEVELOPMENT IN ICELAND

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### ABSTRACT

Iceland is very rich in renewable energy resources in comparison to the need of the country, mainly hydro power and geothermal. Energy usage was, however, very limited through the centuries, but increased rapidly during the last century. Presently these resources supply over 80% of the country's use of primary energy which is the world's highest share of renewables in a national energy budget. Still, only a small fraction of these energy resources has been utilized. The Icelandic Government decided in 1997 to develop a Master Plan for all potential power projects in hydro and geothermal. All proposed projects should be evaluated and categorized on the basis of energy efficiency and economics, as well as, on the basis of the impact that the power developments would have on the environment. The work was organized by a Steering committee of 16 members and some 50 experts nominated for four working groups. The Master Plan is comparable to the planning of land use and land protection. It was not supposed to go into the details required for environmental impact assessment (EIA), but still finding those projects that are best suited for developments based on energy production, economy and protection of the nature.

It is expected that some 100 projects will be evaluated and ranked in the Master Plan. The work is divided into phases. The first phase was completed in 2003 and work on phase 2 is underway. Forty three proposed projects, 19 hydro and 24 geothermal, were evaluated and ranked during phase 1.

### 1. INTRODUCTION

Iceland is an island in the North Atlantic just south of the Arctic Circle. The island lies across the Mid Atlantic Ridge, the rift zone along the constructive boundary between the American and the Eurasian tectonic plates which move apart at an average rate of 2 cm per year. Iceland resides on a mantle plume and a hot spot in the rift zone and has been formed in frequent volcanic eruptions continually from Miocene time to present. This explains why this part of the ridge rises above sea level and forms an island of an area larger than 100.000 km<sup>2</sup>. The highest mountains rise to an elevation of 2000 m and over 50% of the country lies above an elevation of 400 m a.s.l. Several large icecaps are found in the highlands. The presently active zone of rifting and volcanism crosses Iceland from southwest to northeast. Volcanic eruptions are very frequent in this zone and take place typically every few years. The Icelandic crust is therefore very young on the geological time scale and rocks on the surface range in age from zero near recently active volcanoes to 15-16 million years in the coastal areas furthest away from the volcanic zone.

Iceland has abundant energy resources, both hydro and geothermal. The hydro power is associated with the high precipitation and the mountainous terrain of the country. The ice caps can be considered

as water reservoirs and glacial rivers constitute the highest hydropower capacity (Figure 1). The geothermal resources are closely associated with the volcanic activity. Traditionally, the geothermal fields are divided into *high-temperature fields*, where temperature above 200°C is found above 1 km depth and *low-temperature fields*, in which temperature is lower than 150°C in the uppermost kilometre. Some 30 high-temperature fields have been identified in Iceland, all within the active volcanic zone as shown in Figure 2. The low-temperature activity is highest on the flanks of the volcanic zones but some low-temperature resources are found in most parts of the country.

## 2. ENERGY CONSUMPTION IN ICELAND

The utilization of the energy resources of Iceland was very limited through the centuries. Hot water from warm springs was, however, used locally in some areas for bathing, cooking and washing and sulphur was mined from a few of the high-temperature areas and exported to Denmark. It was, however, not until the late 19<sup>th</sup> and early 20<sup>th</sup> century that the Icelanders started to make an effort to utilize the hot springs and experiment with different utilization schemes. This included heating of houses, swimming pools, and soil heating for growing vegetables. The first large development occurred in 1930 when a district heating system started operation in Reykjavik supplying hot water to a hospital, a school, a swimming pool, and some 70 homes. The utilization grew gradually over the next decades. Initially, the geothermal development focused on the utilization of low-temperature resources for space heating. Later, utilization of the high-temperature resources for electrical generation, space heating and some industrial uses followed.

Electric power was first produced in Iceland in 1899, and the first hydro power turbine started production in 1904. The installed capacity was 9 kW. The power plant was built and owned by a carpenter and the energy was used in his workshop, in his household and in a few neighbouring houses. Several small electric power plants became operative during the next decades, most of them driven by hydro. In 1934, the total installed capacity was about 5 MW in 38 power stations. The electrification of the country continued both in urban areas and rural areas. The first power intensive industrial user was the State Fertilizer Plant in 1953, and the first aluminium smelter started production in 1970.

An overview of the primary energy consumption in Iceland during 1940 until 2007 is shown in Figure 3. It shows a dramatic increase in the energy consumption from about 5 to 205 PJ per year. It also shows that in 1940 most of the energy was obtained by burning coal. In 2007, on the other hand, 66% of the primary consumption is geothermal, 15% is hydro, and the rest is mainly oil for the transportation sector and the Icelandic fishing fleet (19%). The development during this 66 years period can be divided into phases. The first phase lasted until 1970 when the main emphasis was on the electrification of the country, mainly by hydropower, and replacement of coal, turf and wood in space heating by geothermal where it was easily accessible and oil and electricity in other areas. The second phase started in the late 1960's when power intensive industry became a large user on the electric market. The third phase is related to the oil price crisis in the 1970's. Due to the dramatic rise in the oil prices the Icelandic Government launched a major effort to replace oil in space heating with geothermal and electric energy. At this time, oil accounted for about 50% of the space heating market, and geothermal for about 40%. The effort was very successful. Ten years later oil heating was down to 5 % and presently geothermal energy serves 90% of the market. The fourth and the final phase which is still ongoing is the large expansion of the power intensive industry after 1995, which in 2004 consumed about 60% of the electricity generated in Iceland.

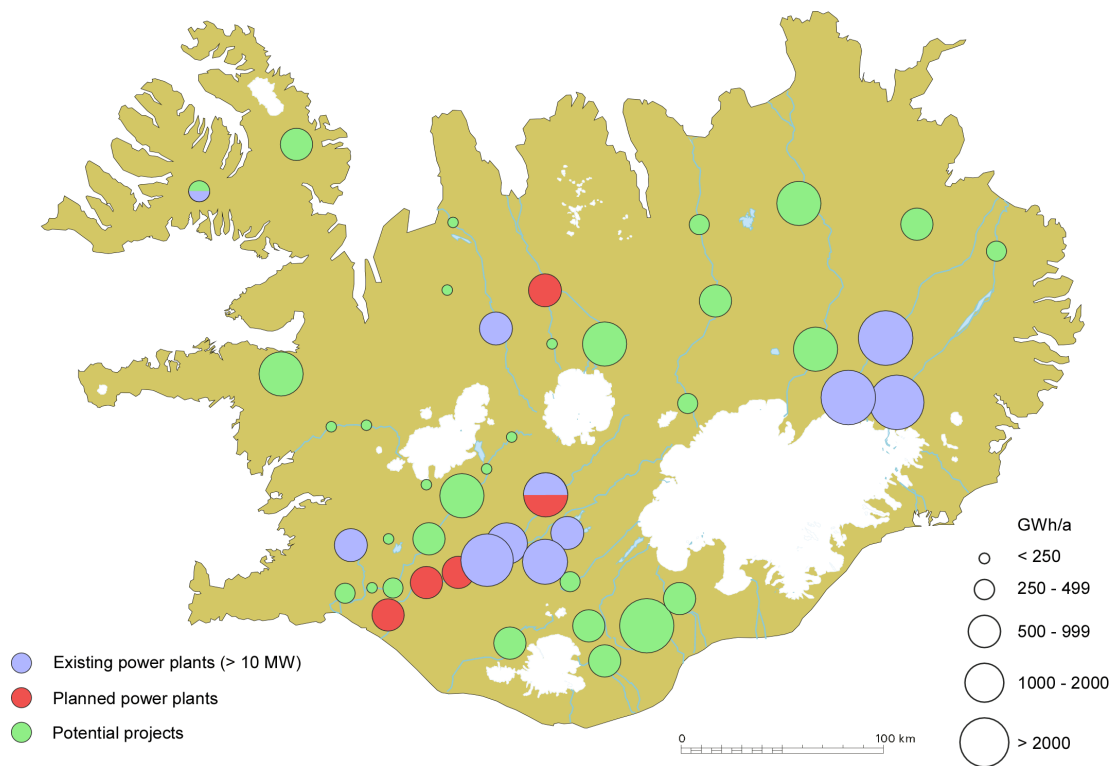


FIGURE 1: Hydropower resources of Iceland. Existing power plants (>10 MW) are shown as blue bullets, planned power plants as red and potential projects as green bullets

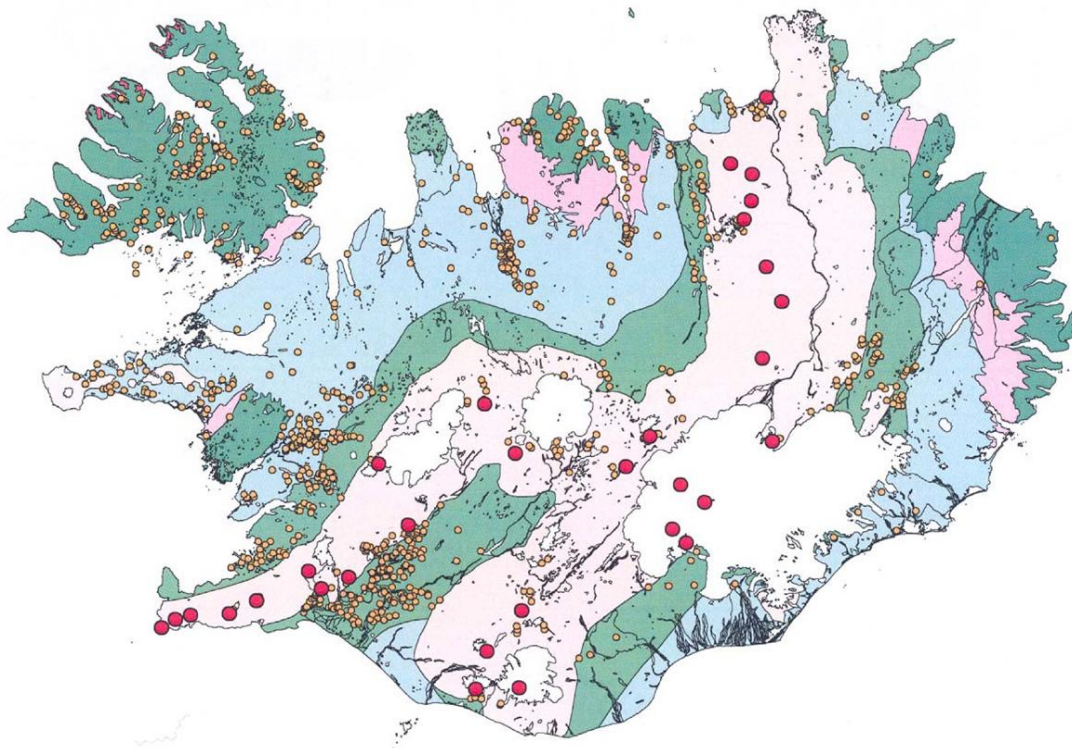


FIGURE 2: Geothermal map of Iceland. High-temperature fields inside the active volcanic zone are shown as red circles, and hot and warm springs as yellow circles

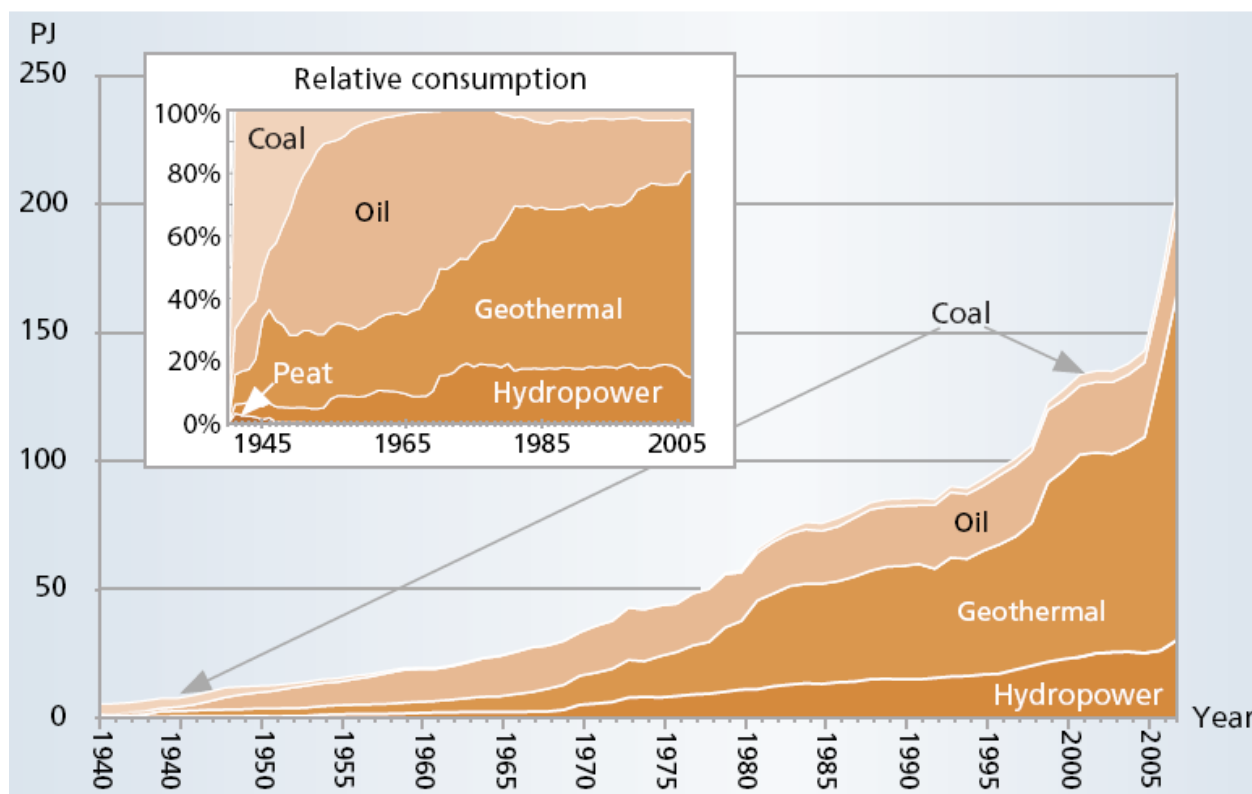


FIGURE 3: Primary energy consumption in Iceland 1940-2007.  
Source: Orkustofnun (National Energy Authority)

### 3. MASTER PLAN FOR THE DEVELOPMENT OF ENERGY RESOURCES

#### 3.1 Need for a Master Plan

Iceland is very rich in renewable energy resources for heat and electricity generation. The potential generating capacity of hydro and geothermal has been estimated at 50 TWh/year. The power generation in 2006 was about 20% of the estimated potential. The Icelandic energy market is, however, developing very rapidly. Two geothermal power plants (190 MW) came on line in late 2006 and 63 MW of geothermal power was added in 2007. The Karahnjúkar hydro project (690 MW) was commissioned in December 2007 and this year the Hellisheiði geothermal power plant will be expanded from 113 to 203 MW. With these new plants in operation it is estimated that, in 2008, the total hydro power generation will be about 40% of the hydro potential, and the geothermal power close to 23% of the total geothermal potential. This is about 32% of the total potential of both sources.

Earlier energy developments in Iceland were focused on meeting the basic energy needs of the society for space heating and electricity for the general market. Through the years it has become more and more evident that utilization of energy resources (as other development) must take into account not only the energy needs and the economical aspects of the development, but also a range of other interests as well. This includes other use of land and the impact of the development on the environment and the cultural heritage. The first step towards such an evaluation was undertaken by a collaboration committee of specialists from the Ministry of Industry, the National Power Company, Orkustofnun (the National Energy Authority) and the Nature Conservation Council. This committee was active during the 1970's to the 1990's. It discussed plans for various electrical power plants with special emphasis on the natural conservation aspects of the projects. It was commonly mentioned during meetings that a general view on the energy policy and the nature conservation policy was needed for the country. The need for a general plan on energy development became even more

important by 1994 when the Parliament of Iceland passed the first Act on Environmental Impact Assessment.

The Icelandic Government published a white paper on sustainability in the Icelandic society in 1997 (Government of Iceland, 1997). There the need of the development of a long term plan for energy use in Iceland was once again stressed.

### **3.2 The Master Plan**

Following the white paper it was decided by the Government to develop a master plan for the utilization of the energy resources, both hydro and geothermal, as a part of its goal for sustainable development. The vision behind the master plan was to prepare an overview of the various potential energy projects in hydro and geothermal and to evaluate and rank these based on their energy and economic potential and the estimated impact that each project would have on nature, the environment and the society.

The master plan should be based on the best available scientific information and conclusions should be transparent and reproducible and made available to the public. It was considered of vital importance to establish public confidence in the evaluation process and therefore the National Association for the Protection of the Icelandic Environment (an NGO) was assigned to establish a forum for the public and interested parties to discuss and exchange information in open meetings and workshops, and to cooperate with the media. Information on the work was also accessible on interactive websites.

The master plan should define those power projects that rank high from an economical point of view, have a minimum negative impact on the environment, and a positive impact on the society. Such a score card for the energy projects helps decisions makers to filter out which of the proposed projects are likely to become controversial and disputed and which ones not. It also directs the attention to those project areas that might have protective value and should be left untouched by human development.

### **3.3 The organization of the Master Plan**

The Ministry of Industry is responsible for the master plan in co-operation with the Ministry for the Environment. A special Steering Committee of 16 members was established in April 1999 for the first phase of the project. In its function it was supported by about 50 experts working in four different working groups.

The members of the Steering Committee were appointed by the ministers of industry and the environment. It included representatives of the two ministries and their key institutions, the chairmen of each of the four workgroups, people involved in local government and representatives of tourist industry and of NGO's. The committee was chaired by Prof. Sveinbjörn Björnsson, director of the Resource Department of Orkustofnun and former rector of the University of Iceland. The duty of the Steering committee was to define the projects and to coordinate the work and the working methods of the working groups which carried out the main part of the work. The working groups collected available data on the various projects and project areas and suggested further data collection and needed exploration work which was then evaluated by the Steering Committee and passed on to Orkustofnun for decision and execution. The Steering Committee worked jointly with the working groups in finding ways for their evaluation of the proposed energy projects. The conclusions of each of the working groups were analyzed by the Steering Committee and their ranking of the projects evaluated and combined to define a general ranking table for all the energy projects evaluated by the working groups. The Steering Committee held monthly meetings and called regularly for public meetings to inform on the progress of the master plan and to obtain suggestions and comments from interested parties. The public meetings were not only held in Reykjavík but also in the regions of proposed power projects to ease the participation of all interested citizens.

Orkustofnun was the main organizing agency and Dr. Hákon Adalsteinsson, chief project manager at the Resource Department at Orkustofnun, worked closely with the Steering Committee and its chairman during the development of the master plan. In between Steering Committee meetings the chairman and the two ministerial representatives operated as an executive board of the committee.

#### **4. THE DEVELOPMENT OF THE MASTER PLAN - PHASE 1**

In 1997 the government expected that the master plan would be completed in year 2000. Preparations were, however, delayed and the work did not start until 1999, so it was evident that the initial time limit could not be met. It was also clear that the development of the plan was not a straight forward process. A similar work had not been carried out before in Iceland and the only foreign example known to the Icelanders was the Norwegian Master Plan for hydropower development which was first developed in 1984 (Environmental Protection department, 1984).

The initial steps in the development of the Icelandic master plan were that Orkustofnun and the power companies compiled reports on project proposals they wished to have evaluated by the Steering Committee. These reports were made available to the public and interested organizations to give them an opportunity to review the reports and offer comments. It soon became evident that the number of proposed projects that should be evaluated and ranked during the master plan work would be about one hundred. Available data for many of the project areas were scarce and it was obvious that the evaluation of all these projects would call for a large investment in data collection and exploration, before all projects could be ranked. The Steering Committee, therefore, suggested to the government to divide the work into phases. For the first phase, 43 energy projects were selected. These were 19 hydropower projects with an energy potential of 16,600 GWh/a and 24 geothermal projects with an energy potential of 18,000 GWh/a. The hydro projects were mainly in glacial rivers in the central highlands, whereas most of the geothermal projects were in geothermal fields near to inhabited lowlands. Phase 1 was completed in 2003. (Steering Committee for the Icelandic Master Plan, 2003). The following paragraphs give a summary of the work during the first phase.

##### **4.1 Working group I - Nature, Environment and Cultural Heritage**

Working Group I constituted 13 experts nominated by the ministries, relevant institutions and NGO's. The chairman was Dr. Th. E. Thórhallsdóttir, botanist and Professor of the University of Iceland. The working group evaluated what impact proposed power projects would have on nature, landscape, geological formations, vegetative cover, flora and fauna, as well as cultural heritage and ancient monuments.

The working group reviewed existing data for each proposed project and divided them by quality into three categories; good (A), fair (B) and unsatisfactory (C), and suggested several data collection tasks in order to improve the knowledge base for the project areas. To rank the proposed projects the working group considered several ways of carrying out the evaluation and selected eventually a three step procedure using multi criteria analysis. The first step was to assess site values, then in the second step the impact of the development was evaluated, and finally in the third step the proposed projects were ranked from worst to best choice from environmental-cultural heritage point of view using analytical hierarchical process using site values and predicted impacts.

The working group decided to identify the components in the natural environment and the heritage that have a considerable value and divide them into 5 classes, four regarding the environment; (1) Geology and hydrology, (2) Species (fauna and flora), (3) Ecosystems and soils, and (4) Landscape and wilderness. The fifth (5) class represented the Cultural heritage. Two of the classes were further divided into subclasses. To evaluate the value of each class and to assess the impact of the power development on these, the valuable properties of the classes were analyzed and assessed through six attributes i.e. properties that are considered to make the classes valuable. The attributes considered

were: (1) Richness-Diversity; (2) Rarity; (3) Size-Pristinity; (4) International responsibility; (5) Information value, and (6) Visual or scenic value.

The classes and the attributes define the evaluation matrix shown in table 1. Each of the 30 elements (attributes) in the matrix was evaluated for each power project area, and its value represented by a value number on a non-linear four point scale: 1=insignificant; 3=some; 6=large and 10= very high value. A similar scale was used for the impact with the addition of the 5th score number 0= no impact. The value score for each class was then found using the weight numbers shown for the attributes in the matrix. Finally the classes were assigned weight factors to reach a unique one number score for each project area. The weight factors were: 25% for Geology and hydrology, 25% for Landscape and wilderness, 20% for Ecosystems and soils, 20% for Species, and finally 10% for Cultural heritage. A detailed account of the work of Working group I is given in two publications by Prof. Thórhallsdóttir (Thórhallsdóttir, 2006a and 2006b).

TABLE 1: Evaluation matrix for environmental and cultural heritage values of the project areas and for assessment of the impact of the developments.  
(Numbers indicate weight numbers for the evaluation).

Classes	Sub-classes	Attributes					
		Richness and diversity	Rarity	Size and Pristinity	International responsibility	Information value	Visual and scenic value
Geology and Hydrology	Bedrock	0.5		0.3		0.2	
	Sediments	0.5		0.3		0.2	
	Hydrology	0.5		0.3		0.2	
	Rivers and lakes	0.5		0.3		0.2	
Species		0.4	0.4		0.2		
Ecosystems and soil		0.3	0.3	0.2	0.1	0.1	
Landscape and wilderness	Landscape		0.2	0.2			0.3
	Wilderness		0.2	0.8			
Cultural heritage		0.2	0.3	0.2		0.3	

#### 4.2 Working group II - Recreation, Fishing, Hunting and Agriculture

Thirteen experts were nominated for Working Group II, which was chaired by Dr. Haukur Jóhannesson, geologist and President of the Iceland Touring Association. This working group evaluated the impact on outdoor life and activity. They recognized three main classes: (1) Recreation, (2) Fishing and hunting, and (3) Grazing and other land use, and divided them into sub-classes. The value of each class was described and analyzed but no score assigned to the value of the classes. The impact of the proposed power development was on the other hand evaluated using an analytical hierarchical process similar to the work of Working group I. An evaluation matrix was defined (table 2) and the impact assessed for the sub-classes, and a scoring number assigned to them on a non-linear five point scale from positive to negative impact. The scale selected was: +3= positive impact; 0=no impact; -1 small; -3 significant, and -5 for major negative impact. The scoring of the sub-classes and then the classes were weighted according to the numbers shown in Table 2 to reach a final score for the impact of the proposed projects on the premises of Working group II.

TABLE 2: Evaluation matrix for the classes and sub-classes of Working group II.  
(Numbers indicate weight numbers for the evaluation)

Classes	Weight number of classes	Sub-classes	Weight number for sub-classes
Recreation	0.72	Short hiking trips.	0.10
		Long trips to the countryside	0.13
		Bird watching and nature observations	0.17
		Adventure trips.	0.13
		Cultural heritage	0.10
		Pony riding trips.	0.10
		Winter trips	0.10
		Enjoyment	0.17
Fishing and hunting	0.19	Fishing in rivers.	0.37
		Fishing in lakes.	0.46
		Hunting	0.17
Other use of land	0.09	Grazing.	0.95
		Other benefits (Useful plants, berries and other)	0.05

### 4.3 Working group III - Social and Economical Impact and Regional Development

Working group III was chaired by Mr. Sigurður Gudmundsson, planning expert at the National Economic Institute and the thirteen group members included experts nominated by economical institutes, Icelandic Federation of Unions, as well as of Employers, the Planning Agency, the Icelandic Tourist Board, the Association of Local Authorities, and others. The task of the working group was to evaluate the impact the proposed power projects would have on economic activity, employment, and regional development.

The Working group developed a model to simulate the impact and tested it for ten proposed power projects. Their conclusion was that the projects could not be ranked regarding to the local impacts of the construction of the power plants. The group evaluated on the other hand the power projects and assessed if the energy produced would be utilized locally and ranked the projects accordingly. The group also developed a model to evaluate the effect of the power development on tourism. This was a comparative study where the tourism was modelled with or without the power development, and power projects which were likely to have the greatest impact, positive or negative, on the tourism could then be identified.

### 4.4 Working group IV - Identification of Potential Power Projects, Project Economy

Working group IV was chaired by Dr. Thorkell Helgason, the director general of Orkustofnun and the six group members were nominated by Orkustofnun, the Icelandic Association of Energy Companies (2), the National Power Company and the Association of Local Authorities (2). The task of Working group IV was to identify potential power projects, both hydro and geothermal, and carry out technical as well as economic evaluation of the projects. The Working group considered four classes for the size and the economics of the projects. These were: (1) Energy capacity (GWh/a), (2) Capital cost per energy unit produced (kr/kWh), (3) Total profit, and (4) Rate of return of investment.

The estimated generating capacity was very different for different projects. Largest was a hydro project with a generating capacity of 4670 GWh/a but smallest was a geothermal project of only 140 GWh/a. The generating capacity of the hydro power plants depends on the flowrate of the river and the reservoir capacity to manage the flowrate evenly throughout the year. The typical geothermal power plant analysed by Working group IV was a 120 MW plant operated for 7000 h/a. The capacity



of the typical geothermal plant was therefore 840 GWh/a. Investment cost was based on 2003 prices. Annual operational cost was estimated 0.8% and 2% of the investment cost for hydro and for geothermal, respectively. Energy prices were estimated for priority and non-priority sales and total profit was estimated for 50 years of operation. The economical calculations showed that the capital cost per energy unit produced was quite similar for most of the projects proposed for the first phase of the master plan. A possible explanation of the similarity might be that during the last decades the hydro projects have been evaluated to be competitive to present projects, and in the case of geothermal projects important cost different factors like the number of boreholes for the given 120 MW units were set constant in poorly evaluated projects. To rank the projects it was therefore decided to look neither at the total investment nor the capital cost per energy unit, but to define an index of likely total profit for the projects. The project of highest profit was assigned the profit index 10, and other projects got an index based on their profit relative to the highest scorer. Similarly, the working group assigned an index of rate of return to the projects.

#### 4.5 Phase 1 - Summary of Results

Forty three potential power projects were evaluated during phase 1. These were 19 hydropower projects with an estimated total power capacity of 16.6 TWh/a, and 24 geothermal projects with an estimated capacity of 18 TWh/a. The Steering Committee analysed the results of the four working groups and decided to use three indices for ranking the projects. These indices are (1) Index U of environmental value and impact that was based on the ranking of Working group I and II, rating the ranking of group I double against the ranking of group II; (2) Index H for total profit over 50 years operation and (3) Index A for rate of return of initial capital cost. Both index H and A were defined by Working group IV. The projects of small environmental impact got a low U-value, but the projects of maximum profit and rate of return got maximum index values. The index scoring was divided into five groups as shown in table 3.

TABLE 3: The indices and index groups to rank the power projects

Groups	Index (U) Environmental Impact	Index (H) Total profit	Index (A) Rate of return
a	0-0.9	10-5	10-5
b	1-2.4	4.9-1.15	4.9-4.0
c	2.5-3.9	1.14-0.9	3.9-3.4
d	4.0-7.9	0.8-0	3.3-2
e	>8	<0	<2

Table 3 formed the basis for the final ranking of the 43 power projects evaluated in phase 1 of the master plan. The greatest interest was in ranking the projects after the environmental impact index. The result was that nineteen of the projects have relatively small environmental impact and fall into group a. Only four of these are hydropower projects and the rest are geothermal. There are 9 projects in environmental group b are nine projects, 3 geothermal and 6 hydro. Four projects were ranked in environmental group c, 7 in group d, and 4 hydropower projects were ranked in environmental group e. The ranking of the power projects shows clearly that geothermal power projects were considered to have much less environmental impact on Icelandic nature than hydro power projects.

## 5. THE MASTER PLAN - PHASE 2

The second phase of the master plan was launched in September 2004 when the second Steering Committee was appointed. This time the committee consisted of three persons, the chairman of the Steering Committee of phase 1, and a representative from each of the two ministries, Ministry of Industry and Ministry of Environment. Its mandate was provisional (until beginning of 2007) to secure further gathering of information for a similar evaluation as in phase 1. The committee worked

closely with the institutions of the ministries, mainly Orkustofnun (the National Energy Authority) and the Icelandic Institute of Natural History. In phase 2, the focus is on the exploration of the active geothermal systems in the central highlands of Iceland and the methodology of geothermal reservoir assessment in order to compare the various geothermal reservoirs and then re-evaluate all the geothermal project areas. The pioneering work on how to evaluate landscape that Working group I started during phase 1 were continued in phase 2, together with an attempt to map the landscape features and evaluate them. Other main characteristics of high-temperature geothermal areas which will be used for the environmental ranking are connected to their geological nature and their biota. Finally, the potential in the general hydrological runoff for mini hydro stations in Iceland will be evaluated (Adalsteinsson, 2006).

The second Steering Committee consulted two groups. One to evaluate methods applied to assess the biological and geological nature of geothermal fields and the generating capacity of geothermal reservoirs, and the other to advise on how to improve the methodology in evaluating landscape with emphasis on the landscape characterizing the geothermal areas.

The consultancy groups have worked hard during the last four years and have put forward several exploration and data collection programmes, some which are now being executed. The main work tasks that will be carried out in phase 2 are:

1. Exploration of the unexplored geothermal areas in the highlands. This includes geological mapping, geophysical exploration, and sampling of fluids from hot springs and fumaroles in each area. The ultimate goal of the exploration is to develop a conceptual model of each geothermal system, estimate its size and probable reservoir temperature.
2. Geothermal projects from the first phase will be re-evaluated, together with the new areas evaluated in phase 2.
3. Classification of geothermal manifestations and colourful altered ground found in the geothermal areas. Evaluation of the protection value of these.
4. Mapping of the special vegetation found near the geothermal manifestations and the microbiota found in the hot spring areas.
5. Methods to evaluate Icelandic landscape and make a comparison with similar methods applied in Europe in order to divide landscape into various classes.
6. Small and mini hydros. There are many possibilities of small hydro stations in Iceland, but the potential is neither well known nor easy to determine. During phase 2, it was decided to participate in setting up a digital run-off model for Iceland. In collaboration with the Freshwater Fishery Institute a biological characterization of running waters was carried out to classify their protection value.
7. Re-evaluation of modified hydro- and geothermal projects from phase 1, based on improved field data, and applying revised methodology. Evaluation of additional projects that have been prepared for evaluation since phase 1.

A third Steering Committee of eleven representatives was appointed in August 2007 to fulfil the evaluation of the projects dealt with in phase 2 in a similar manner as the phase 1 projects. After that all necessary data have been collected this winter the former working groups will be re-established, at least groups 1, 2 and 4 (see chapter 4). In addition, a group of specialists from Orkustofnun, ISOR, the universities in Iceland and the power companies will evaluate and define sustainability of the utilization of the geothermal fields.

The second phase is expected to be completed in 2009. It is hoped that the combined results of the two phases will establish a database, which classifies the potential hydro- and geothermal projects into a category with small environmental impact, a category with significant environmental impact but however likely to be realized when other projects have been accomplished, and a third category of projects that have such a large environmental impact that they should hardly be undertaken. This classification will be brought up in the Parliament for confirmation.

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